THIN FILM FUSE LINK

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Abstract

The operating characteristics of a compact style of substrate fuse link will be presented. The fuse consisted of an alumina substrate with a combination of single layer screen printing and vapour deposited silver film that formed the element. The fuse link had a nominal current rating capacity of 63 Amps and was tested both at low and high overloads. In addition capacitor bank tests were also performed which tested the fuse link's ability to clear a DC short circuit. The new fuse links had a shorter operating time when compared with the conventional semiconductor fuse of similar rating.. From the "captured" current-voltage characteristics, there is a sharp cutoff to the short circuit current with no overshoot which gives a more symmetrical current waveform. The largest performance gain is in the lowering of the I^2t let through when compared with a conventional fuse link. In general there was a factor of seven improvement when using a substrate fuse. However, for high overload currents, this improvement increased to a factor of 19. These results show that this type of fuse link demonstrates some clear advantages for the protection of sensitive semiconductor devices.

1. Introduction.

Semiconductor protection requires very fast acting, current limiting fuselinks for which various designs have been developed. Most of these designs have evolved from the basic industrial fuselink. This has led to the development of fuselinks which attain rapid operation with low let-through I^2t. So far this has sufficed for the protection of most semiconductor devices. The next generation of electronic power devices such as IGBT's are much more sensitive to the effects of fault conditions and so require even faster acting fuselinks.

It is generally believed that the conventional semiconductor fuselink is reaching the limits of its development and so there is a need for a radically different design. The approach chosen here was to investigate the applicability of substrate fuselinks for the protection of power semiconductor devices. In a conventional fuselink the fusing region of the element is sufficiently thin so as to enable quick operation in the event of a fault but sufficiently thick so as to maintain mechanical rigidity.To achieve much faster operation the dimensions of the fusing region have been reduced sigificantly. In a substrate fuselink this is achieved by making the elements only a few micrometres thick and mounting them on an electrically insulating and thermally conductive ceramic substartes, which provide essential mechanical support. The substrate acts as a heatsink drawing heat away from the element under normal running conditions. This paper reports on the operating characteristics of such a fuselink.

2. Manufacture.

Details on how the fuselinks were manufactured have already been reported in detail [1] and so only a brief introduction is given here. The fusing region of the fuselink elements were made by thermally evaporating high purity silver on to an alumina substrate. Two designs of fusing region were used in this work. These are shown in **figure 1.**

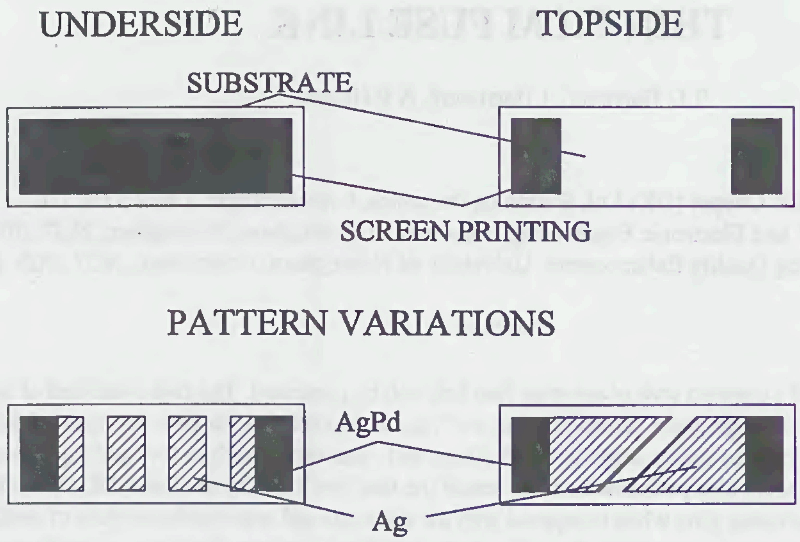

Figure 1 Element Configuration

The silver thickness in this region was 1μm unless otherwise stated. The rest of the fuselink element, comprised of a silver screen printed pad. The resistance of the screen printed areas was sufficiently low so as not to play a role in the fusing action of the element. The underside of the substrate was also provided with an area of silver screen printing which allowed the element and substrate to be soldered to a copper baseplate. Connecting tags were soldered to each end of the element and the whole assembly encased in a plastic body and carefully sand filled. Provision was made in the base plate to allow the fuselink assembly to be bolted to a heatsink. This arrangement is shown in **figure 2**.

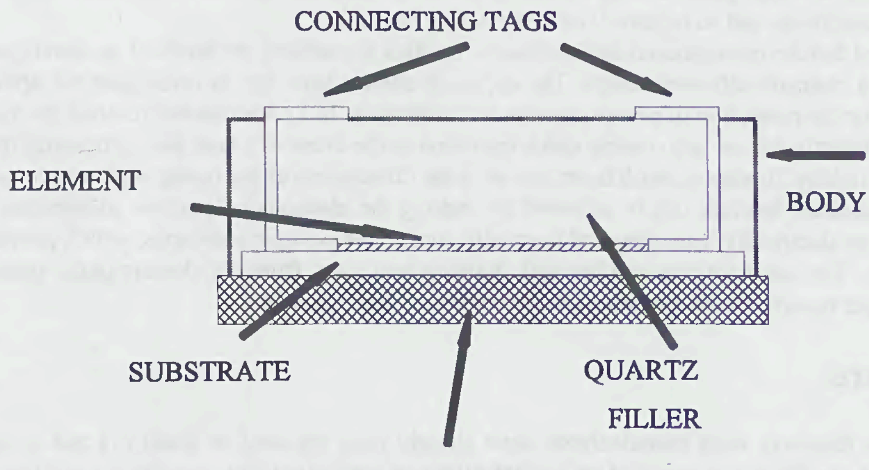

Figure 2 Physcial arrangment of the fuselink.

3. Current Rating of Fuselinks.

The current ratings of the substrate fuselinks were determined by established methods and the resulting time current curves can be seen in **figure 3** compared with fuselinks from one of Bussmann's conventional semiconductor protection range. The assigned current ratings of the substrate fuselinks along with other parameters can be seen in the **table 1** and one can see the relatively large power loss of this type of fuse.

Fuselink	Rating Amps.	Cross Section mm^2	Power Loss Watts	Minimum I^2t A^2s [2]	Current Density A/mm^2
1 μm 3 Notch	63*	$1x10^{-2}$	150-200	8	6300
2 μm 3 Notch	90*	$2x10^{-2}$	60-100	31	4500
1 μm 1 Notch	120*	$2x10^{-2}$	175-220	31	6000
20LCT	20	$2x10^{-2}$	4	25	1000
63LET	63	$4.8x10^{-2}$	9	185	1300
80LET	80	$6x10^{-2}$	10	285	1330
125LET	125	$12x10^{-2}$	16	650	1040

Table 1 showing the properties of the different kinds of fuselink used in this experiment. The Power loss, minimum I^2t and current density are at the rated currents.

4. Short Circuit Performance.

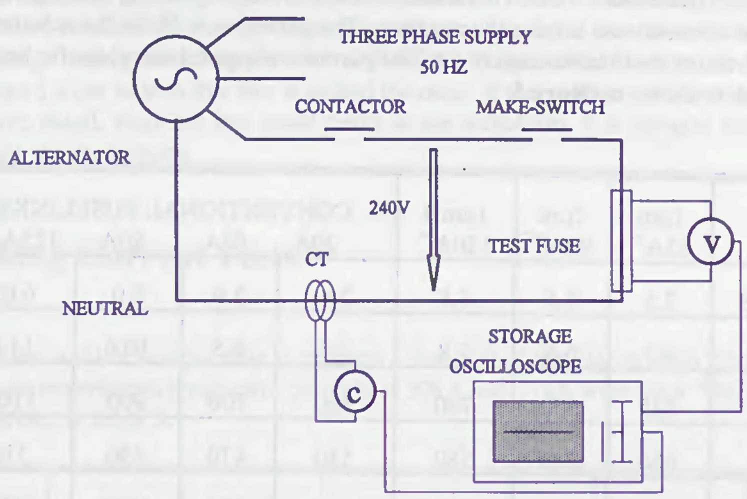

Figure 4. Short circuit arrangment.

To measure the actual I^2t let-through, some short-circuit tests were performed. Unlike the pre-arcing time, the arcing time depends strongly on the voltage applied to the fuselink and the power factor. To simulate the most severe conditions the fuselinks were tested in a single phase inductive circuit with a low power factor of less than 0.2. A point on wave controller was used to ensure consistency of switching of the circuit. These tests measured not only the operating time but also the I^2t, arc voltages and cut-off currents. The experimental setup is shown in **figure 4**.The prospective current was set at 660A rms. The results of these tests are given in **table 2**. From this table it can be seen that the substrate fuselinks respond rapidly to the short circuit. For example, if one considers the 1 μm fuselink compared with a

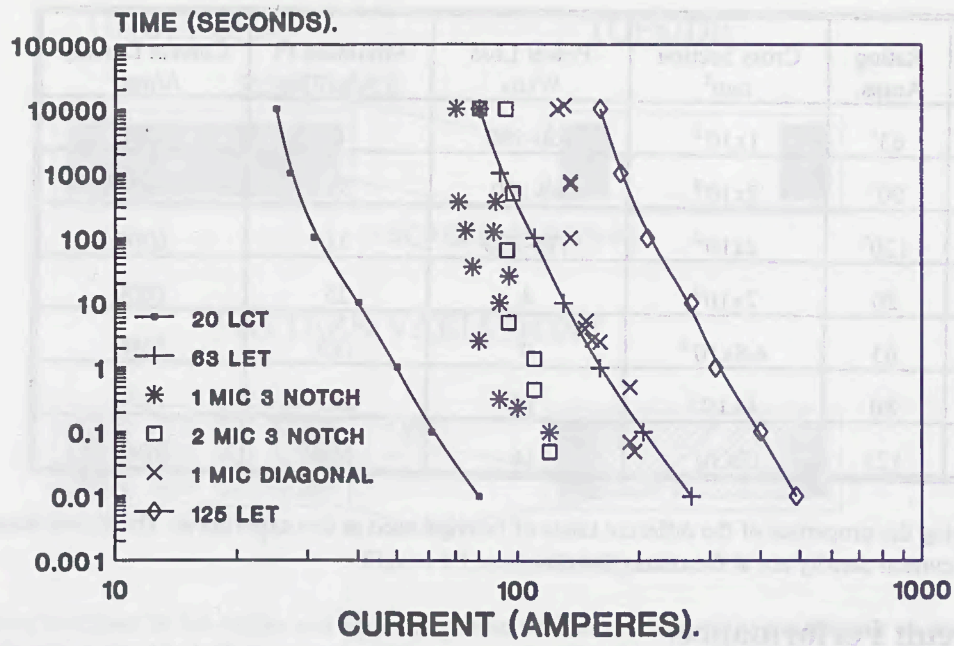

Figure 3 Time Current characteristics

conventional semiconductor (Bussmann - 63LET) fuselink, then the average operating time for the substrate fuselink is approximately half the conventional semiconductor fuse. The reduction in I^2t for the substrate fuselinks is even more dramatic where the ratio of the I^2t let-through is 1:8. The current-voltage relationships for both the substrate and the conventional fuselink is shown in **figure 5**.

	1μm 63A**	2μm 90A**	1μmD 120A**	CONVENTIONAL FUSELINKS* 20A	63A	80A	125A
PRE-ARC TIME mS	2.5	3.5	3.5	2.4	3.9	5.0	6.05
TOTAL TIME mS	4.7	6.6	7.8	7.5	9.5	10.6	11.0
PEAK I Amps	425	600	700	300	700	900	1100
PEAK V Volts	660	610	580	530	470	490	510
PRE-ARC I^2t A^2S	200	540	740	90	955	1600	3500
TOTAL I^2t A^2S	380	1130	1380	230	2815	4220	8250

* 240 V Semiconductor range from Bussmann. ** Assigned rating

Table 2 Results of the short circuit tests.

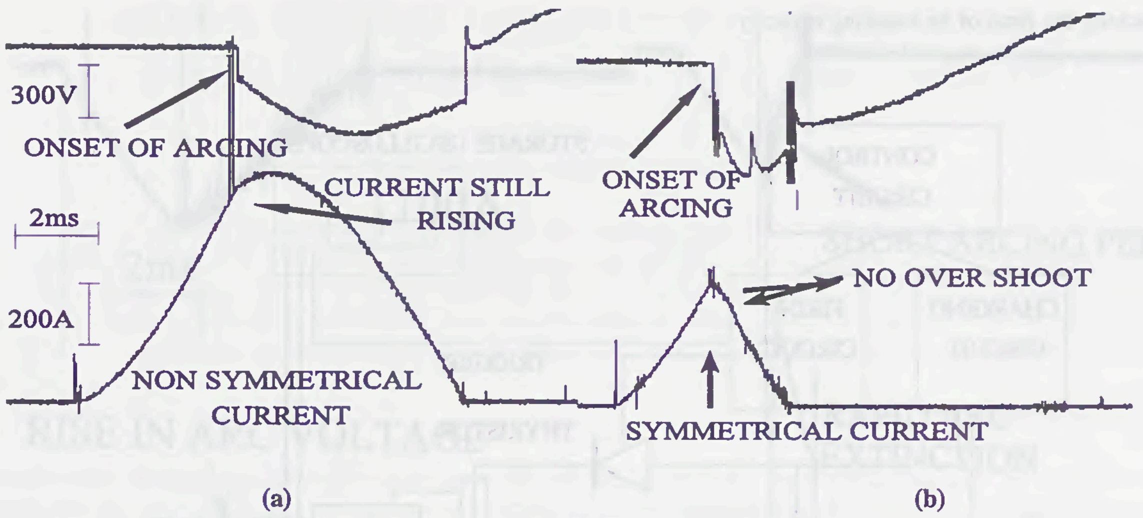

Figure 5 Comparison of characteristics of a) 63LET Bussman fuselink and b) 63A substrate fuselink. The top trace is voltage waveform and the bottom waveform the current. The time,voltage and current scales are the same for each diagram.

It can be seen from **figure 5**. that in the conventional fuselink the current continues to rise briefly before falling whereas in the substrate fuselink the current drops immediately. Since the current reduces faster in the substrate fuselink, then the voltage during the arcing period is higher than the conventional fuselink due to the inductance of the circuit. From figure 5 it can be seen that this is indeed the case. If the voltage waveform of the substrate fuselink is considered in more detail, there are two small peaks in the waveform. It is thought that this may arise due to multiple arcing within the restrictions.

5. High Breaking Current Tests

During the course of this work it was possible to perform a few tests at the Falcon short circuit testing laboratory in Loughborough. In these experiments prospective currents of 30kA and 17kA were used. The experimental data from these tests is summarised in **table 3.**

TEST NUMBER	4916	4917	9806	9810	63 LET
PROSPECTIVE	29.3 kA	29.3 kA	17.0 kA	17.0 kA	30 kA
APPLIED VOLTS	265	265	245	245	240
POWER FACTOR	0.15	0.15	0.17	0.17	0.12
PRE-ARC TIME	0.06 mS	0.04 mS	0.9 mS	0.74 mS	< 1 mS
TOTAL TIME	3.3 mS	3.2 mS	1.17 mS	1.05 mS	2 mS
PRE-ARC I^2t	19.7 A^2S	19.5 A^2S	60 A^2S	86 A^2S	270 A^2S
TOTAL I^2t	166 A^2S	171 A^2S	80 A^2S	122 A^2S	3200 A^2S

Table 3 Results of High Short Circuit Tests. The fuselinks used in the first four test were 1um 3 notch substrate fuselinks. The last column gives the results for a 63A Bussmann LET fuse.

The tests performed at prospective test current of 17.0kA appear to show similarities to those described at a prospective current of 660A. However, at the higher prospective current of 29.3kA, the tests show that the arcing time is abnormally long. This observation may be caused by one of two effects. The filler surrounding the fuselink elements may have not been sufficiently packed, or at 29.3kA this particular design of substrate fuselink may be approaching the limit of its breaking capacity.

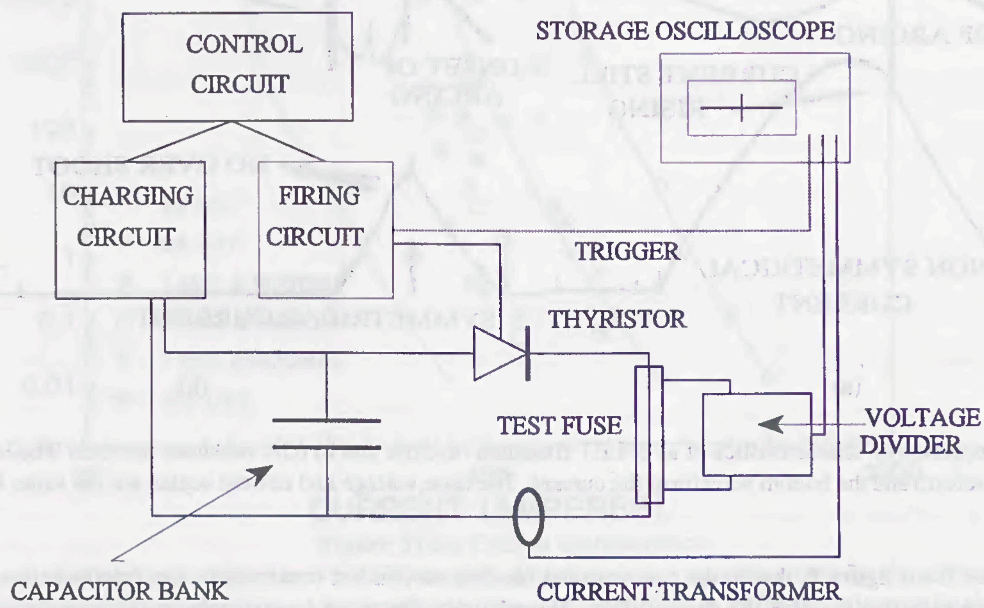

Figure 6 Capcitor Bank Arrangement

6. DC Tests

One of the most demanding tasks for a fuselink is the clearing of a direct current fault. To investigate the ability of the substrate fuselink to clear such a fault, tests were performed on a capacitor bank. See **figure 6**.

In essence these tests involve charging a large capacitance and discharging it through the fuselink under test. The results are presented in **table 4**. These results show that in terms of operating time, I^2t let-through the substrate fuselink performs better than the conventional fuse. As with the a.c. test, the peak voltage across the fuselink increases. The current voltage characteristics are very different for the two types of fuses. These characteristics are shown in **figure 7**. In the substrate fuselink the arc is quenched very rapidly.

	1μm 63A	2μm 90A	1μmD 120A*	CONVENTIONAL FUSELINK 20A	63A	80A	125A
PRE-ARC TIME mS	3.6	4.8	7.1	2.3	5.1	6.5	9.1
TOTAL TIME mS	5.8	8.0	15.0	17.4	21.2	25.8	26.4
PEAK I Amps	365	460	525	260	525	700	930
PEAK V Volts	710	800	410	400	400	320	370
PRE-ARC I^2t A^2S	220	500	980	80	700	1600	3900
TOTAL I^2t A^2S	360	980	1800	320	2570	5300	9500

* Diagonal restriction.

Table 4.Results of the D.C. Tests performed with a prospective Current of 1500 Amps and a time constant of 13ms.

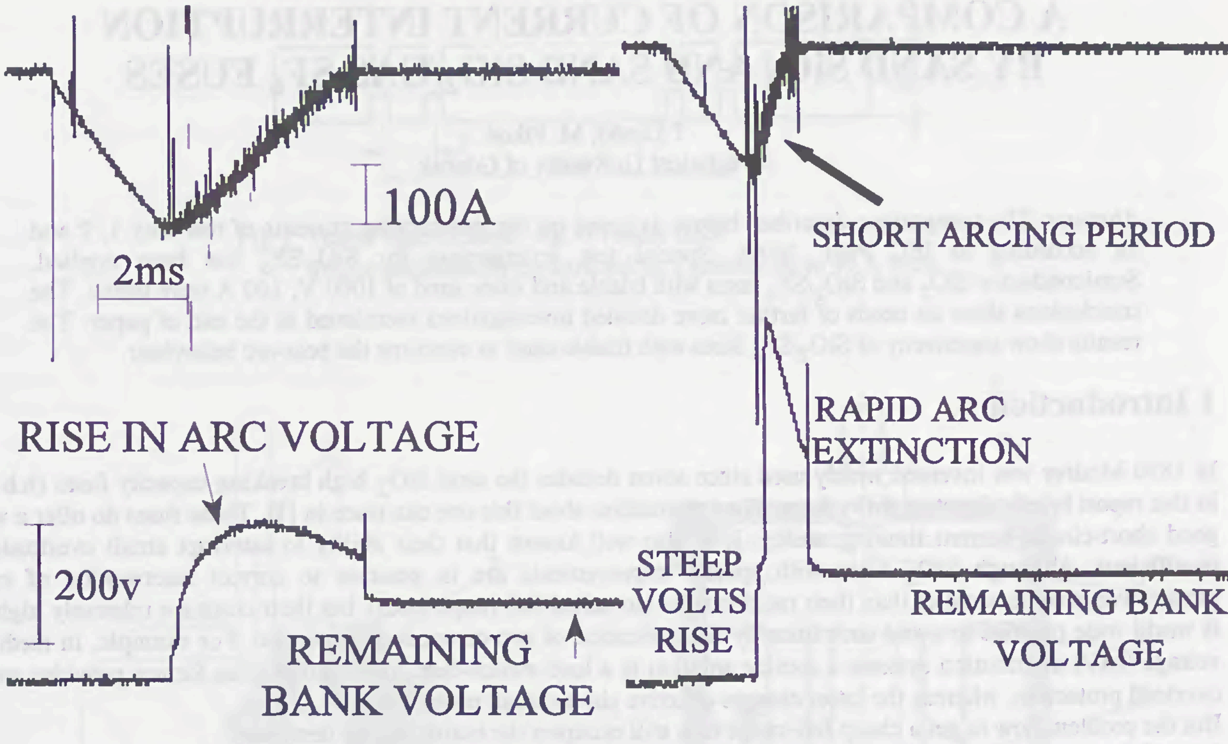

Figure 7.Current (upper trace) and voltage waveforms (lower trace) of a) Bussmann 63 LET fuselink and b) substrate fuselink. The voltage ,current and time scales are the same for each diagram and are shown on the lefthand side of diagram a..

7. Conclusion

The results described in this work show conclusively that substrate fuselinks operate significantly faster than conventional fuses. The current and voltage characteristics show that during operation of the fuselink, there is a sharp cut-off to the current with no overshoot and a clear end to the arcing period with no re-strikes. Since there is less material in the fusing region, there is less metal to vaporise and so the I^2t is corresponding less. An unavoidable characteristic of the substrate fuselink is the rise in peak voltage caused by the inductance of the circuit and the rapidly changing current. One factor which has not been commented on and needs addressing before the substrate fuselink can be developed into a practical fuselink is its relatively high power loss.

In conclusion substrate fuselinks operate faster than coventional fuselinks and with a I^2t let-through which is approximately an order of magnitude less than that of traditional designs of a similar current rating.

8. References

1. R. Harrison, I. Harrison, A.F. Howe 'Ageing of film fuses on substrates',, Proceedings of the fourth International Conference on Electric Fuses and their applications, Nottingham, September 1991.

2 J.W. Gibson, 'The high rupturing capacity cartridge fuse with special reference to short circuit performance', J.IEE 88 (1941) pp 2-24.